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VISTA NF-16D PROGRAMMABLE DISPLAY SYSTEM DEVELOPMENT

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ABSTRACT

Wright Laboratory's Variable-Stability In-Flight Simulator Test Aircraft (VISTA) NF-16D is the newest in-flight simulator in the USAF inventory. This unique research aircraft will perform a multitude of missions: to evaluate flight characteristics of new aircraft that have not yet flown, to perform research in the areas of flying qualities, flight control design, pilot-vehicle interface, weapons and avionics integration, and to train test pilots and engineers. The VISTA is being upgraded to enhance its simulation fidelity and its research capabilities through the addition of a programmable helmet-mounted display (HMD) and head-up display (HUD) in the front cockpit. The programmable helmet-mounted display system consists of a GEC-Marconi Avionics Viper II Helmet-Mounted Optics Module integrated with a modified Helmet Integrated Systems Limited (HISL) HGU-86/P helmet, the Honeywell Advanced Metal Tolerant tracker, and a GEC-Marconi Avionics Programmable Display Generator. The monocular HMD system is designed for growth to stroke-on-video, binocular capability. Lessons-learned in the VISTA HMD development are reviewed. An outline of the proposed VISTA HMD demonstration flight is given to highlight the VISTA programmable displays system capabilities.

Keywords: Helmet-Mounted Displays, Head-Up Displays, Flight Test, Programmable Display System, Head Tracking, Primary Flight Reference, Symbology Development

1. BACKGROUND

The VISTA NF-16D aircraft is an in-flight simulator, which means that it can duplicate the flight characteristics of other aircraft. In-flight simulation has the same basic functionality of a ground simulator only it allows a much more realistic evaluation because the pilot is in real flight, with the real motion and visual cues. VISTA was developed by a joint Lockheed/Calspan SRL team and delivered to the Air Force in 1995. Since then, it has simulated the F-22 and Indian Light Combat Aircraft, performed special instruction flights at the Air Force and Navy test pilot schools, and conducted several flight control research efforts.

In-flight simulation and the VISTA research support functions are made possible (and affordable) by the addition of a second flight control system called the Variable Stability System (VSS), which operates in parallel with the normal F-16 control laws. The VSS is hosted in three Rolm Hawk 32 ruggedized airborne digital computers. The VSS is engaged once the VISTA is in the air and commands, with essentially full-authority, the NF-16D left and right horizontal stabilizer, ailerons, thrust, rudder, and trailing edge flaps. The front seat pilot flies the F-16 through the second control system and will feel like he is flying the simulated aircraft or experimental control laws. The back seat pilot is the safety pilot and can take-over control of the VISTA at any time. This concept allows experimental configurations to be tested with safely and without extensive software validation and verification.

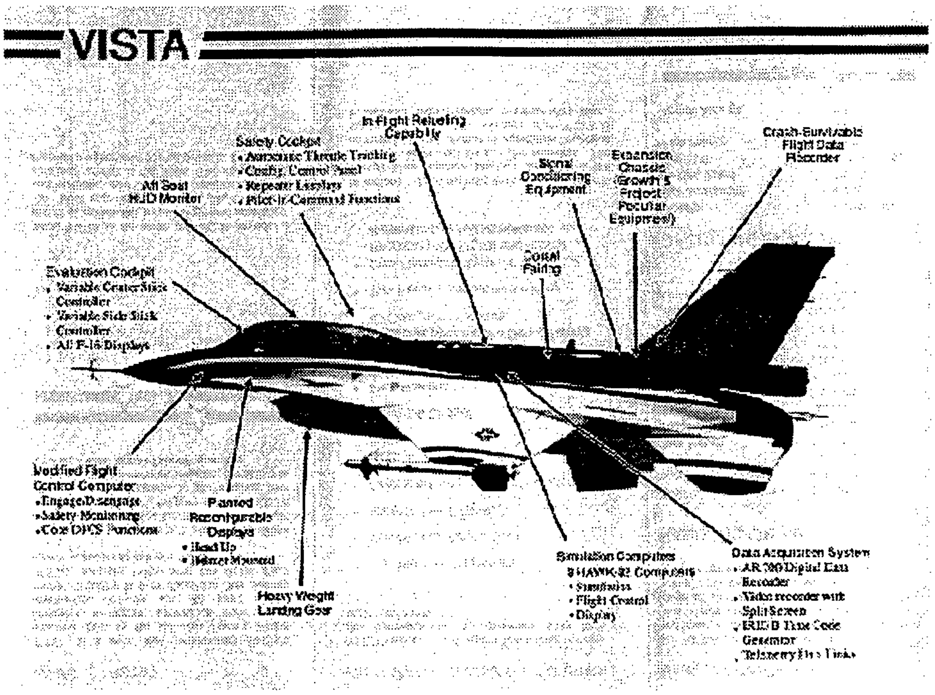

FIGURE 1: VISTA OVERVIEW

2. VISTA PROGRAMMABLE DISPLAY SYSTEM

The VISTA Programmable Display System (PDS) was initiated to upgrade the VISTA aircraft capability for in-flight simulation research and training; specifically:

1) As an in-flight simulator, the PDS will generate the displays and display response characteristics of simulated aircraft for proper replication of the pilot-vehicle system.
2) As a research and development, test and evaluation asset, the PDS will support the needs of cockpit display technology development by having significant baseline capability as well as providing upgrade and growth paths.
3) As a training platform, the PDS will have the capability for a wide range of formats and options during a single training flight with in-field programmability.
4) As a test asset, the PDS will be able to enunciate status conditions and states as well as improving the situational awareness of the safety pilots, who also serve as the experimental systems operators.

All of these capabilities must be provided in a timely and affordable fashion. Therefore, the PDS was designed to leave safety-of-flight unaffected and changes to the PDS can be implemented on-site quickly and easily.

The VISTA PDS is sketched in Figure 2. This system is described fully in Reference 1 and is briefly described in the following:

- A GEC-Marconi Programmable Displays Generator (PDG) is the heart of the PDS. The PDG communicates via 1553 bus interface with the Hawk computers over the VSS bus (the so-called V-Mux) and provides the interface, processing, and communications required to support the programmable HUD and HMD systems. The PDG utilizes an F-16 HUD Electronics Unit (EU) chassis with key technology inserted from the GEC F-22 displays development, including two 1750A processors to generate the processing power for the programmable HUD and stroke-only HMD.[2]

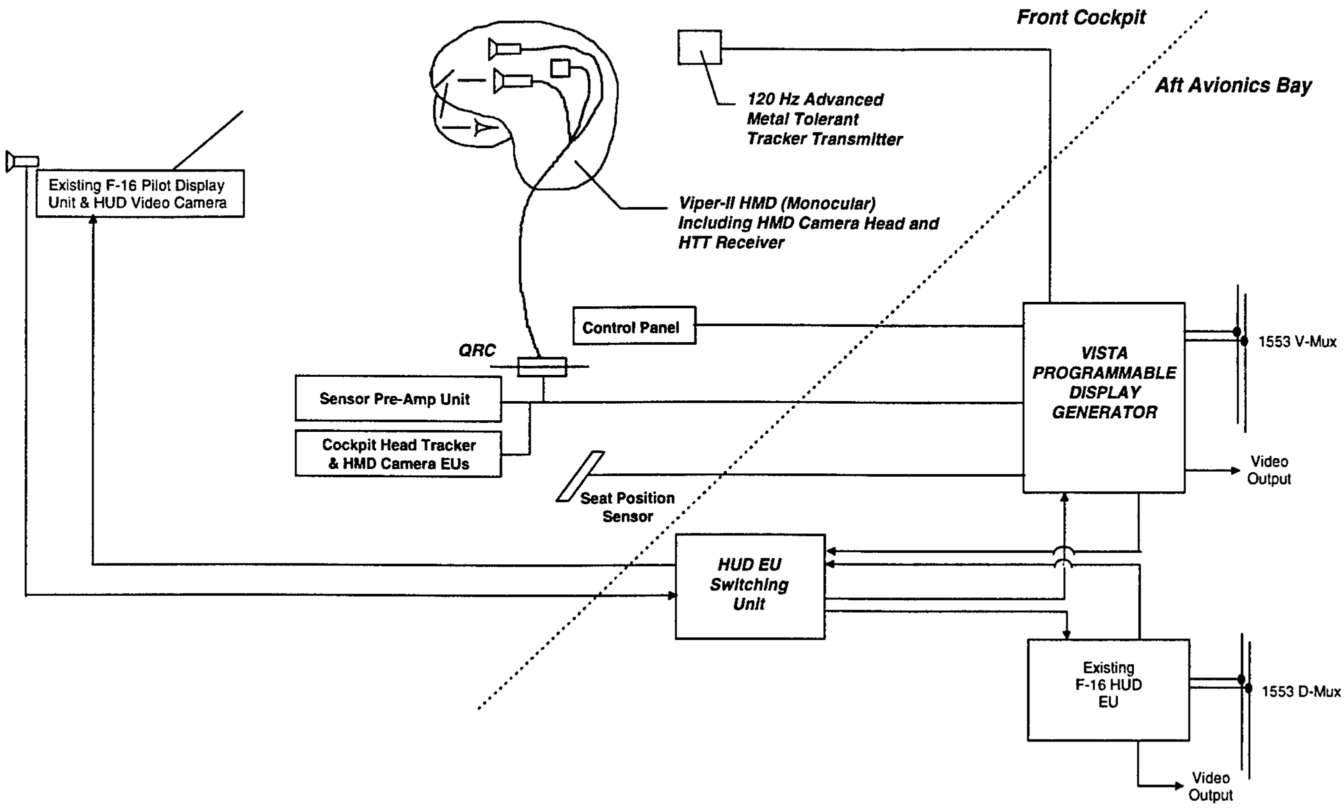

FIGURE 2: PROGRAMMABLE DISPLAY SYSTEM

- A HUD EU Switching Unit has been designed and built to drive the standard F-16D HUD Pilot Display Unit (PDU) with either the VPDG or the F-16 HUD EU outputs in stroke-only or stroke-on-raster modes. When the PDU is displaying the programmable HUD, the F-16 HUD EU is kept active and can be displayed by the rear cockpit safety pilot on the ASHM or recorded on video tape for post-processing and flight review. The programmable display HUD symbology, like the F-16 HUD symbology, is combined with the HUD video camera output and recorded on video tape.

- A modified Viper-II HMD provides a 40 degree Field-of-View (FOV) monocular visor-projected, installed on a slightly modified HGU-86/P helmet shell. The medium size HGU-86/P should accommodate approximately 80% of the population, but if this size is still not acceptable, the modular Viper-II VISTA system can be quickly transferred and flown on another size HGU-86/P. The ear cup and nape tensioning and fitting system of the HGU-86/P should provide a stable platform for the HMD optics without slip or discomfort under g-loading.

- A commercial off-the-shelf color video camera head is installed under the visor of the Viper-II to capture the pilot's view with overlay of the HMD symbology as video output from the VPDG. This HMD video is recorded for post-flight review and can also be displayed in real-time on the rear cockpit safety pilot's MFD or ASHM.

- The Honeywell Advanced Metal Tolerant tracker has been integrated into the VISTA PDS HMD system.[3] The tracker has been optimized for synchronized communications between PDS subsystems, thus minimizing transport delay and generating an integrated product.

- The 120 Hz AC head tracker transmitter is installed in the front cockpit of the VISTA. The helmet tracker receiver is (non-permanently) attached to the HGU-86/P helmet. A control panel, cockpit unit, and sensor pre-

amp units are installed in the right front console of the VISTA to interface to the VPDG. Seat position sensing is used in the head tracker algorithms.

- For VISTA, the head tracker transmitter is mounted on a non-metallic stalk (fixture) to the right side and slightly aft of the front seat evaluation pilot. The stalk mount, attached to the canopy sill, has the benefit that the transmitter location will not be influenced by canopy closing variations. Getting the transmitter off-the-canopy simplifies canopy maintenance, precludes visual obscurations due to tracker installation, and eliminated a potential safety-of-flight hazard caused by the possibility that the transmitter mount might fail in the (unlikely) event of a birdstrike.

3. LESSONS-LEARNED

Many decisions were made during the course of the VISTA PDS procurement and its development. With 20/20 hindsight, these decisions can now be reflected upon as lessons-learned in the hope that this history can be learned and not repeated by others. Although this development program was unique in that it was intended for a research aircraft with programmability/versatility a premium, these lessons may be useful in development and procurement of production systems as well. The lessons-learned that are told are the opinions of the authors and do not necessarily represent their respective companies, the United States Air Force, or the sponsors of this work.

At the time of this writing, system delivery and installation have just begun. Operational useage of the system is scheduled for May 1998.

3.1 Requirements Definition

One of the first hurdles that was encountered was the lack of definitive system and performance requirements. System requirements could not be defined *a priori* but evolved in the course of source selection because the budget was essentially the only requirement. An "off-the-shelf" system procurement was clearly essential. The cost and availability of these systems dictated the vast majority of the requirements.

Requirements evolution of this sort was not necessarily a problem - it was a recognized fact - but it did invoke a substantial amount of consternation and continual re-evaluation of goals, missions, issues and the like for people who were unaccustomed to dealing with this type of procurement.

What was know about the system requirements were:

- Research Priorities:
  The capability to perform the future research, test, and training mission of the VISTA aircraft was critical. Affordability, which goes hand-in-hand with the VISTA mission, was an unwavering requirement.

- System Re-programmability:
  A wealth of past experience was available from operating a programmable display system on the (now-retired) USAF NT-33A aircraft. Unfortunately, it was difficult to define this capability in sufficient detail and clarity on a piece of paper. More often than not, it was a matter of demonstrations and briefings. This was not a very effective process but it was effective considering that paper definition alone would probably have produced an ineffective and limited programmability.

- Growth Potential:
  Growth provisions were deemed critical. It was not considered to be a viable solution if the procurement led to a dead end. On the other hand, growth provisions cost money and could be very costly particularly in the era of uncertain, at best, and declining, at worse, budgets, if the growth provisions are never exercised or if the lag between procurement renders the provisions obsolete. Growth provisions were selected, again, on a cost vs. benefit relations; For instance:

◊ The need for a single helmet (one with both monocular and binocular) or two helmet systems (i.e., one helmet for monocular and one helmet for binocular) was actively debated. In the end, the cost for binocular in either a single or two helmet system was prohibitive. However, the Viper-II system allows a relatively easy and low-cost upgrade to the module for binocular. The VISTA Viper-II HMD optics module includes provision for the second, binocular Cathode Ray Tube (CRT) even though only one is currently used in the monocular HMD. Also, a 40 deg FOV display on the HMD may be "over-kill" for day VFR applications, but this FOV was considered on the VISTA development as a minimum desired FOV for a binocular HMD system. Of course, with the 40 deg FOV in the day VFR application, the VISTA PDS can always simulate smaller FOVs than a 40 deg by limiting the symbol area. This gives considerable flexibility for research, test, and training, at only a minimal increase in head-mounted weight.

◊ Wiring provisions for binocular was also seriously considered but rejected. Given 20/20 hindsight, this decision was excellent. Cost and uncertainty in this growth provision were the reason for its initial rejection and given the course of the program, these two items would have been even worse than the initial projections. The cost and program turmoil for binocular growth wiring could have killed the PDS development.

3.2 Helmet Selection

In the procurement process, three helmet types were available for selection on which to install the Viper-II module. These were: 1) HGU-55/P; 2) HGU-53/P; and, 3) the HGU-86/P. The primary issues associated with this selection were: a) weight; b) pilot comfort/acceptance; c) HMD compatibility; and, d) logistics.

After considerable debate, the HGU-86/P was selected for the VISTA Viper-II HMD. This decision was based primarily on its lightweight, its compatibility for HMD applications, and its preferred logistics:

- Weight considerations favored the HGU-86/P or the HGU-53/P. At the time of procurement, lightweight versions of the HGU-55/P were being considered for development, specifically for HMD applications, but a production decision was not at hand. Consequently, the lightweight 55/P was not considered to be viable since the cost for a one-off procurement and its flight-qualification was prohibitive.

- Pilot comfort and acceptance favored the HGU-55/P for the USAF VISTA. Within the USAF, the HGU-55/P helmet shell is like motherhood and apple pie. Conversely, the HGU-86/P has the stigma of using an ear cup and nape tensioning method which is foreign to most of the USAF-based piloting contingent. The comfort and acceptance of the HGU-86/P in VISTA will be closely watched. The HGU-53/P was allegedly rejected by the USAF in part because of comfort and acceptance deficiencies. It was rejected for VISTA because of these same concerns.

- HMD compatibility favored the HGU-86/P. While the ear cup and nape tensioning method is unique to most USAF pilots, the stability of the helmet under g-loading and its immunity to Thermo-Plastic Liner-induced deficiencies, such as slippage, poor fitting, and hot spots offer significant HMD application advantages.

- Logistics favored both the HGU-86/P and the HGU-55/P. Clearly, HGU-55/P logistics are not an issue within the USAF. However, re-fitting the VISTA Viper-II HMD with TPLs for US Navy flyers, non-pilots, VIPs, and the like could become a complication, specifically when helmet fit can become a critical determinant in HMD evaluation. The HGU-86/P can be easily fitted and avoids the TPL problem. As the helmet for the F-22, logistics for long-term support within the US will not be a problem, if indeed, this selection comes to fruition.

3.3 Windblast Testing

Windblast testing was a constant supply of surprises in that: 1) the results are difficult, if not impossible, to predict; 2) requirements and procedures for windblast are in a constant state-of-flux; and 3) at best, the results are a comparative rather than absolute analysis.

In the VISTA Viper-II development, several tweaks were applied to accommodate the HGU-86/P helmet shell with the aim of improving windblast protection and test. These improvements were made based on past experience and were intuitively logical. However, hindsight showed that the improvements came with their own downfalls. Some prior, simplified testing and analysis, rather than intuition before windblast would have been beneficial since, once at windblast, the errors become obvious and considerable expense is incurred. After re-fit, the improvements were ultimately beneficial (and quantifiable), but the process to attain these improvements can be improved.

Windblast testing was hampered by "moving goalposts." The windblast test requirements and testing procedures were constantly changing. Likely the cause of immaturity in fielding HMD systems for fighters, this lack of consistency makes it difficult to know what the design requirements are and to know what preliminary testing must be undertaken. For instance, the initial VISTA HMD windblast test was conducted using the wrong size helmet due to misinterpretation of the testing requirements. Uniform procedures and test methods must be established and the efforts being undertaken to do this are welcome.

At best, the windblast results provide a comparative rather than absolute measure since the ejection sequence is not tested and some test limitations constrain its validity. This program is penalized in this respect because it was the first HMD windblast conduct at the F-16 32 deg seat back angle. "Nominal" helmet windblast data must be obtained to perform a comparative measure of the HMD module and comparisons, however fair or unfair, will also be made back to "normal" seat back angle data. Further, the mannequin in the windblast lacked realistic neck articulation. The consequence of this artifact was not quantified but there were numerous concerns since, in combination with the steep 32 deg seat back angle, a significant lift and helmet roll effect is generated which was not "countered" by any seat restraint. It is unfortunate that at present, it is not possible to augment the windblast test, in an economical fashion, to simulate ejection. It is too expensive under a limited "development" effort to gather all of the data necessary to simulate and hence, define the consequences of an ejection.

4. DEMONSTRATION EXAMPLES

An initial definition of a Head-Up Display (HUD) and Helmet-Mounted Display (HMD) demonstation flight in VISTA has been developed. The purpose of this flight is to fly, first-hand, display design concepts, techniques, and testing issues. Previous work in HMD and HUD standardization concepts and demonstrations, as well as new work being done in industry, was considered for demonstration. This demonstration flight has not been finalized and it is always changing. This initial look at this flight profile highlights many of the features of the VISTA PDS.

The demonstration flight is arranged to slowly “build-up” the user’s knowledge, not only in HMD and HUD concepts, but also in familiarity with the VISTA aircraft and its operation. Accordingly, the first few items are less thought-provoking, whereas the latter stages of the flight are more cerebral and complex. The pace and content of the flight is, of course. always tailored to the user.

The major topics of this flight are presented in the following sections.

4.1 HUD-Only Demonstration Concepts

The HUD-Only work begins the demo since the user will more likely have experience with the HUD rather than the HMD. This familiarization will allow the Evaluation Pilot (EP) to get familiar with the VISTA and its operating procedures while evaluating easy-to-digest display concepts. The HUD topics primary address the issues of clutter and display formats on data interpretation and usability by varying the airspeed and altitude formats. For instance, brief maneuvering flight is conducted with airspeed and altitude tapes, digital-only presentations, and "dials" displays (shown in Figure 3a, 3b, and 3c, respectively). Other topics of a general display design nature are also covered.

4.2 HUD Dynamics

The next phase of flight emphasizes the dynamics which drive the symbology are as critical, if not more so, than the display format. This phase of the demo, which again only utilizes the HUD, highlights:

- Pitch vs. Climb-dive vs. Flight path-reference displays
- Caging vs. un-caging references
- Quickening, filtering, and latency in display data

a) Tape Display   b) Digital Display   c) Dial Display

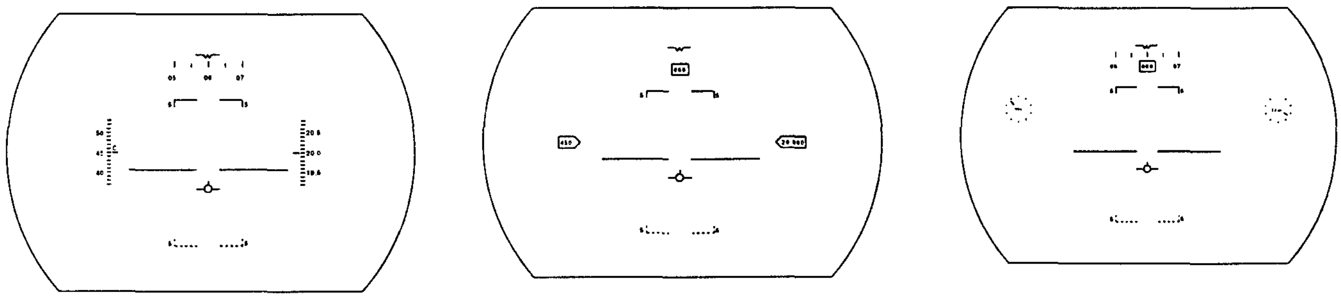

FIGURE 3: HUD FORMAT VARIATIONS

4.3 HUD Attitude Recognition

As a segue from the second and third components of this demonstration flight, HUD field-of-view limiting is shown for conformal flight path and attitude data presentations. This demonstration leads directly into the importance of the "control symbol" for flight reference and how the dynamic response and the format of information cannot be divorced. Further, it builds toward the concept of using a HUD or HMD as a primary flight reference. For instance, climb-dive or flight path referenced HUDs are flown to angles-of-attack greater than the HUD can display conformally. At this juncture, different schemes of displays are shown, such as transition from flight path-reference to attitude reference or maintenance of flight path conformity with attitude non-conformity.

In the next sequence, many of the principals by which the HUD Standards formation evolved (Reference 4-6) are demonstrated. This demo phase illustrates the display characteristics that are critical for "PFR reference qualification," ala MIL-STD-1787. This flight phase emphasizes the principles of display asymmetry for usual attitude recognition and recovery, as shown in Figure 4.

In many of these issues, the high maneuverability of the VISTA NF-16D and its capability to perform safe and effective unusual attitude maneuvers is critical since ground simulation demonstrations do not fully replicate the potential vertigo and disorientation of real flight for which these displays become critical.

4.4 HMD Principals

The fourth phase of the demo starts the HMD concepts demonstrations. The HUD is not used in this section as basic HMD principals are shown, including:

- Reference Frames (HMD-fixed, aircraft-stabilized, and inertial-stabilized symbology)
- Field-of-view and symbology positioning
- Format Examples (to compare and contrast the same symbology used on the HUD but now on the HMD with various frames-of-reference and HMD positioning)

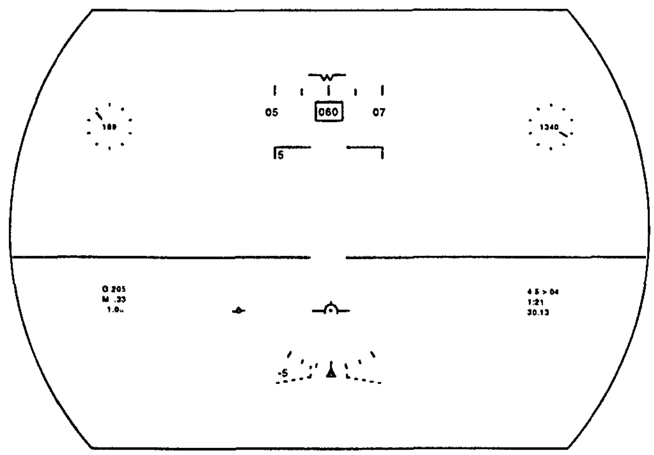

FIGURE 4: ASYMMETRIC HUD FORMAT EXAMPLE

Having evaluated the influence of HUD data dynamics, the HMD issues are compared and contrasted, but this time, the primary issues are concerned with the Head Tracker since it is so critical in an effective HMD system, including:

- Tracker Update Rate: Tracker updates rates are progressively reduced from the nominal 120 Hz down to 15 Hz.

- Latency: The influence of latency in the head position data is shown by adding pure digital delay in incremental amounts to the nominal 8.3 msec of the VISTA tracker system. Up to an additional 150 milliseconds of delay is shown.

- Degraded Head Motion Box: The head tracker output is intentionally degraded in software so that translations of the helmet of more that 1, 2, or 5 inches from the nominal location severely degrade the tracker. This effect is seen in the stabilized symbology.

- Tracker Noise: Similarly, the helmet tracker is degraded in software by adding noise into the tracker data to simulate the influences of electro-mechanical or electrical noise interference in the head tracker system and the HMD optical system.

- Helmet Slippage: Since the integrity of the HMD system is critically dependent upon the helmet fit and boresight, this facet is demonstrated in flight by having the EP intentionally loosening the helmet (by releasing one of the tensioning clamps) and either manually pushing on the helmet to slip it on the head, or performing a high-g maneuver to induce slippage. This illustrates the importance of a good helmet fit when using an HMD. Once this test point is complete, the helmet is re-tightened and an in-flight HMD boresight performed.

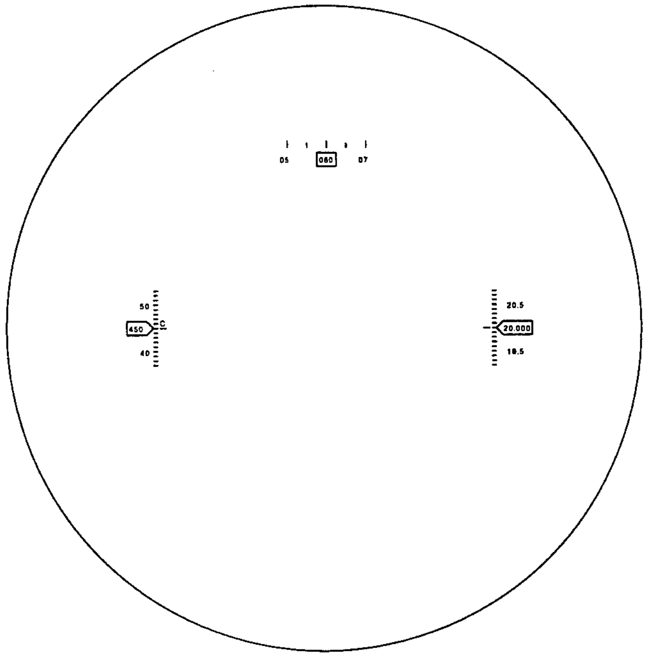

FIGURE 5: "BASELINE" HMD FORMAT

4.5 HUD and HMD Integration

When using an HMD in combination with a HUD, there are numerous important design issues that must be considered to achieve a good marriage of these technologies. These are evaluated as follows:

- No Blanking of HMD
  Using a "baseline" set of HUD and HMD formats, both displays are active at all times. When looking through the HUD, the HMD symbology will not be blanked or occluded; thus, the different displays symbologies will overlay, making both displays difficult to read. In addition, when looking head-down into the cockpit, the HMD symbology will remain displayed.

- Blank HMD when looking through HUD or into cockpit
  This demonstration uses the same HUD and HMD baseline displays but now the HMD symbology is completely blanked whenever any part of the HMD is viewing through the HUD or into the cockpit.

- Occlude HMD when looking through HUD or into cockpit
  A subtle variation is shown where an occlusion area is put around the HUD and cockpit so that only the part of the HMD display surface that conflicts with the HUD is "masked out". A similar technique is used to occlude any portion of the HMD that is into the cockpit.

- Dissimilar formats
  While occlusion zones can be a powerful mitigating aid, dissimilar formats may create a distraction or provide useful cueing. In this demonstration, the HUD format shown in Figure 3c (dials for airspeed and altitude) is used in combination with an HMD of dissimilar format (Figure 5). The HMD is occluded when looking through the HUD but a "cognitive shift" is invoked in interpreting the same data. Conversely, this asymmetry may be useful if it is important to convey differentiation of display device to the pilot in the use of this data or when clutter issues for a display device become preeminent.

4.6 HMD as a Primary Flight Reference

A logical first-step in HMD displays is to add own-ship information into the display for situational awareness. Of particular concern is the addition of attitude information into off-boresight contexts which may, in fact, be counter-productive (Reference 7). This phase of the flight demonstrates several off-boresight attitude presentations for evaluation:

- Pitch-Roll Indicator: Attitude information is added to a nominal HMD format, shown in Figure 6, using a simple stick-figure representation of a attitude indicator.

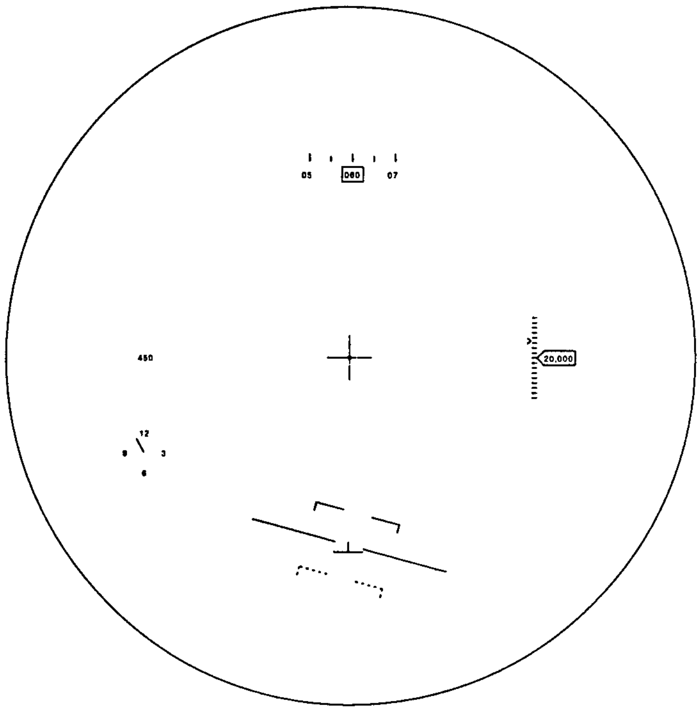

FIGURE 6: "PITCH/ROLL" OFF-BORESIGHT ATTITUDE HMD FORMAT

- Theta Ball: An alternate method for attitude information is provided by a "theta ball". The theta ball is a three-dimensional, line depiction of an attitude direction indicator, including heading, shown in Figure 7. Clearly, this presentation provides more depth of attitude information, but at what cost to the user?

- Arc-Segmented Attitude Reference ("Orange Peel"): In contrast to the previous "attitude direction indicator" representations, the "orange peel" or Arc-Segmented Attitude Reference (ASAR) is demonstrated (Figure 8). The ASAR depicts pitch and roll attitude by the segment arc. The large FOV VISTA HMD is used to show the "Orange Peel" both in a foveal (Figure 8a) and peripheral presentation (Figure 8b), where the moniker has sometimes been changed to "Grapefruit."

Again, the safe and effective high maneuverability of the VISTA NF-16D is critical to the successful evaluation of these display concepts. Without a liberal dose of spatial disorientation, the true capabilities of these displays for attitude reference cannot be determined.

4.7 Virtual HUD

In Figure 9, a simple example of a valid primary flight reference display is taken from the HUD and applied to an HMD such that all data, including the pitch ladder and flight path marker are aircraft stabilized and only appear when looking ahead. Once outside this "virtual HUD" field of regard, a gun cross is shown on the HMD. This is possible one example of using the HMD as a HUD replacement.

In this demonstration, this same HMD format (the "Virtual HUD") is demonstrated with several critical design issues varied, such as: 1) FOV constraints of the virtual HUD (i.e., the CDM, FPM and pitch ladder are displayed throughout their range of azimuth and elevation); 2) Head Tracker Imperfections; and 3) HMD field-of-view changes.

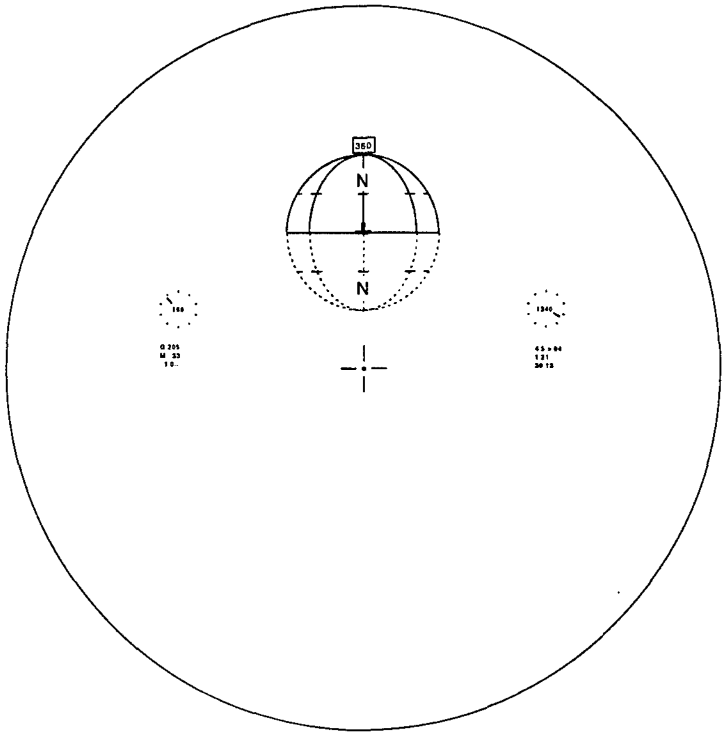

FIGURE 7: "THETA-BALL" OFF-BORESIGHT ATTITUDE HMD FORMAT

a) "Orange Peel" - Foveal Display

b) "Grapefruit" Peripheral Display

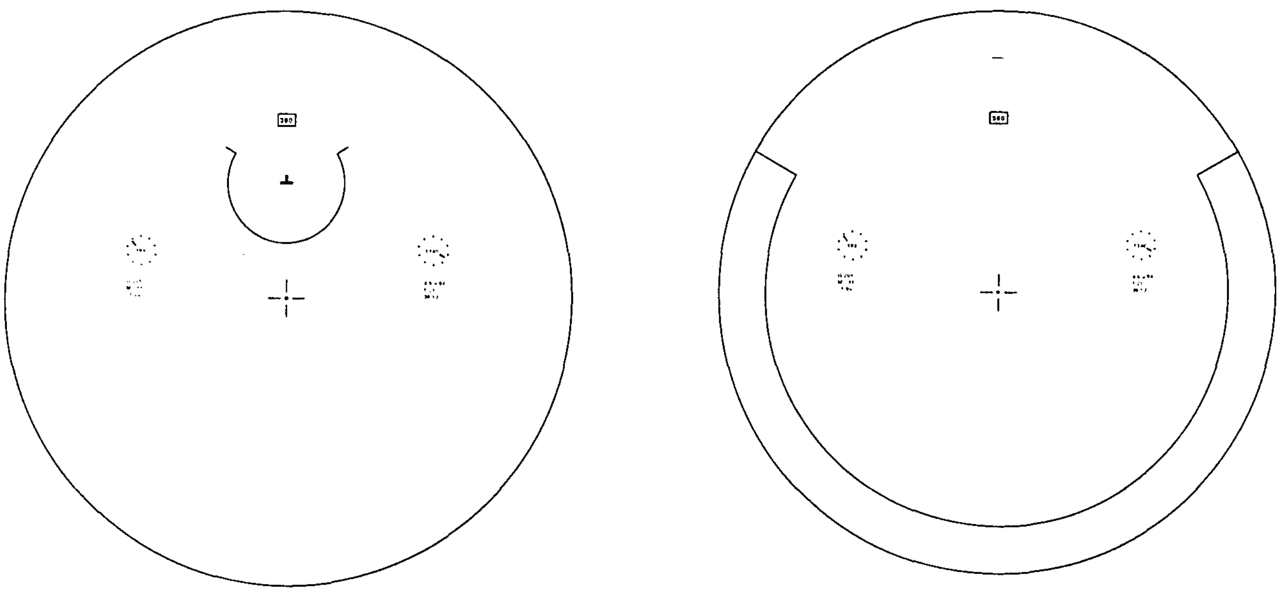

FIGURE 8: ARC-SEGMENTED ATTITUDE REFERENCE

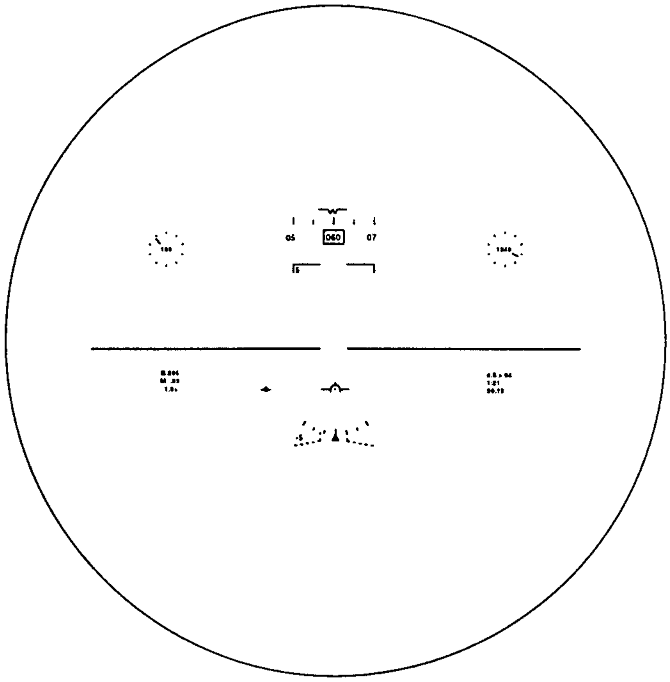

FIGURE 9: VIRTUAL HUD FORMAT (SHOWN ON HMD)

4.8 HMD/Weapons Systems Integration

In the VISTA, the VISTA Viper-II HMD has been designated as a "sensor-of-interest" in the F-16 weapons systems. Thus, the HMD line-of-sight (head tracker orientation) can be used to slave or cue available weapon and seekers on the VISTA aircraft. The following demonstrations show this capability and many of the displays, switchology, and pilot-vehicle interface issues that are critical to successfully employing this technology, such as:

- "Sensor of interest" (SOI) Concept.
  One sensor is designated as the "master" sensor, and all other slave-able sensors will follow that line-of-sight. The "master" sensor can be controlled by the pilot in many situations. The VISTA avionics have been modified to allow the HMD to be the SOI in air-to-air through the display management switch (DMS) on the sidestick controller . Once the HMD is set as the SOI, the target management switch (TMS) on the sidestick allows the pilot to tell the avionics that his line-of-sight corresponds to a desired target. By pressing the TMS up, the line-of-sight is passed to the FCR, air-to-air missile or other slave-able sensor (which will be demonstrated later).

- Fire Control Radar Cueing.

- Air-to-Air Missile Cueing

- Aiming Reticles

5.0 CONCLUDING REMARKS

The VISTA NF-16D Programmable Display System development is nearing completion. Operational testing and research and development usage is planned to commence in May 1998. With this system development, many lessons have been learned with possible feed-through to development programs. Further, significant research and development issues can be quickly and easily addressed with the programmable display capabilities of this unique flight tool.

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